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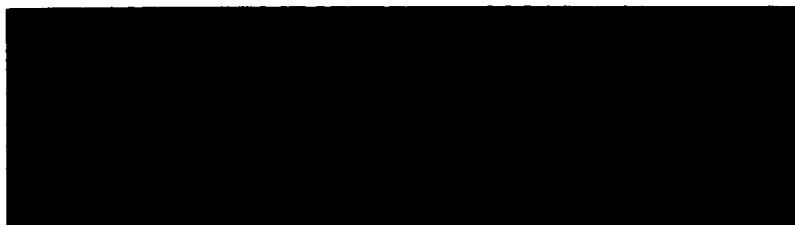
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THE SCIENTIFIC OBJECTIVES OF DEEP SPACE
INVESTIGATIONS

THE SATELLITES OF JUPITER



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THE SATELLITES OF JUPITER

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ABSTRACT

THE SATELLITES OF JUPITER

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This document reports the second in a series of studies being undertaken by ASC/IITRI on the Scientific Objectives of Deep Space Investigations. The satellites of Jupiter are arranged in three distinct groups, the outermost group having retrograde motion. The origins of the three groups are discussed and are followed by a summary of the known physical properties of the satellites. The majority of the available data is restricted to the four largest satellites which are in the group closest to Jupiter and these will probably be the more scientifically interesting in any early missions, particularly as they always present the same face to the parent planet. Despite their short sidereal periods, which makes them quite fast moving targets, they could be useful platforms for observing Jupiter.

The basic measurements which are suggested are (1) visual measurements using photography or television, (2) spectrometry and polarimetry to provide data on the gross nature of the surface, (3) magnetic field measurements in interplanetary space, in the Jovian field and if possible in any local satellite magnetic field, (4) micrometeorite and charged particle measurements particularly as some of the satellites may be very close to the Jovian trapped radiation belts, and (5) biological measurements which will be important if a landing is made on a satellite.

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It is probable that the satellites of Jupiter will not be considered as objects deserving immediate scientific investigation using space probes, and certainly they are not particularly amenable targets to intercept and from which to gain detailed information. The first missions should therefore be linked with more comprehensive missions to Jupiter say, using the time spent near aphelion of a Jovian orbit for location and measurements on the satellites. When landing on small objects is possible at distances as great as 4 AU from the Earth then it will be well worth considering a satellite of Jupiter as a scientific target in itself and a useful observation platform for Jupiter.

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THE SATELLITES OF JUPITER

1. INTRODUCTION

The planet Jupiter has twelve known satellites which have orbital characteristics that divide them into three distinct groups. The earliest known group (Galilean) contains the five largest satellites (numbers 1 to 5) which have direct and nearly circular orbits between 2 and 26 Jupiter radii from the primary. All these satellites rotate at the same rate as they revolve around Jupiter and therefore always present the same face to the parent body.

The second group (numbers 6, 7 and 10) are at a distance of approximately 165 Jupiter radii from the planet but again show direct revolution. The third group (numbers 8, 9, 11 and 12) are approximately 300 radii from Jupiter and show retrograde motion around Jupiter. Both the second and third groups are highly irregular in that their orbits are continually changing due to the conflicting influences of the Sun and Jupiter.

2. THE ORIGIN OF THE SATELLITES

The origin of the satellites of Jupiter is linked very much with the origin of the planets which is discussed in a previous report (Roberts 1963). The two major and basic theories of origin of the solar system have been expounded by Alfven (Alfven 1954, Alfven and Wilcox 1962) and Kuiper (1951a, 1951b). The former theory demands condensation of hot fully ionized

gases with magnetic fields influencing the position of the planets while the latter relies solely on mechanical dynamics. The theory described by Alfven, when extended to the origin of satellites postulates a repetition of the mechanism of the planet formation around the Sun but now, some time later, with the satellites forming around the planets. However Kuiper allows the formation of the satellites during or even before the protoplanet stage.

The grouping of the Jovian satellites indicates separate origins, separate, that is, either in time or in mechanism. The Galilean group are considered as being directly associated with Jupiter and probably as evolving from a condensation process. The possible exception to this is J 5 which is small and very close to Jupiter (2 radii) and may be a late accumulation of condensation products (Kuiper and Middlehurst 1961). The irregular satellites of the other two groups are considered as additions to the Jovian system in that they were probably captured by Jupiter, whether they were originally formed as satellites and escaped or whether they were formerly part of the asteroid belt. If they were satellites which escaped during the rapid evaporation of the protoplanet, then they would have similar heliocentric motion to Jupiter and thus it may be possible for them to be recaptured. In accepting this hypothesis it would also seem possible that some of the large orbit asteroids and particularly the Trojans or Hidalgo may originally have been formed as Jovian satellites. In the capturing of satellites there is an approximately equal probability of the captured satellite having direct or retrograde motion (Kuiper 1956). Further the satellites in the two irregular groups may not individually represent separate

captures but may be fractions of just two captured bodies. For this to be valid it would probably require that they were fairly loose coagulations perhaps even similar to the construction of a comet nucleus.

3. PHYSICAL PROPERTIES OF THE SATELLITES

The majority of physical data obtained on the Jovian satellites refers to the largest four in the Galilean group. The others are more difficult to study because of their small size and because of their ever changing orbits. A table is attached showing the main orbital properties of the satellites.

3.1 Mass and Density

The masses of the first four satellites are 7.2×10^{22} Kg, 4.7×10^{22} Kg, 1.54×10^{23} Kg and 9.6×10^{22} Kg. The others are estimated to have masses at least 2×10^4 less than these. The densities using the above mass figures are 4.03 g/cc, 3.78 g/cc, 2.38 g/cc and 2.06 g/cc for the first four and it can be noted that the density decreases with distance from Jupiter which may indicate an increasing ice or snow content and a decreasing metal and stone constitution.

3.2 Size

The estimated diameters of the satellites are given in Table 1, where it can be seen how much larger the first four are compared to the rest. To put these figures into perspective, J 3 is larger than Mercury, and almost as large as Mars while J 4 is considerably larger than the moon. The smaller satellites are comparable in size to the larger asteroids.

3.3 Brightness

The four group 1 satellites have magnitudes as high as 5 but the rest are ranged from Mag 13 for J 5 to Mag 19 for J 12. It is also possible

that further Jovian satellites exist but that they are too dim to be seen from Earth.

3.4 Color and Albedo

Again only the first four are large enough to be scanned with respect to color and albedo. The color indices (Sun = 0.5) are 1.06, 0.77, 0.64 and 0.68 which all veer to the distinct orange color of J 1. This coloration has not been explained as yet but there may well be some connection with the Jupiter red spot. The albedo varies considerably among the four satellites which respectively are 0.57, 0.60, 0.34 and 0.15.

3.5 Temperature

The satellite temperatures, as estimated from their infrared emission spectra have only been derived for numbers 1 to 4. These are 99°K, 97°K, 110°K and 117°K. These compare with an estimated temperature for Jupiter of 130°K.

3.6 Atmosphere and Surface Properties

All four of the largest satellites are capable of retaining some form of atmosphere and in particular J 3. However no atmospheres were detected in spite of a series of spectral measurements by Kuiper in 1952 specifically arranged to detect the most probable atmospheric constituents. Probably a thin atmosphere does exist. The nature of the surfaces are not accurately defined but are suspected of being similar to the moon. Maria type markings have been seen on the largest four and have been used to determine the rotational period (Lyot 1954). If, however, the group 2 and 3 satellites are fragments, then this will probably be evidenced in the nature of their surface.

3.7 Structure and Composition

The only known densities for the satellites show them to be fairly low but considerably higher than Jupiter itself. The densities and temperatures are commensurate with an icy type of construction and this is suggested for the irregular satellites if they, in fact, have split from larger bodies on approaching Jupiter. Their internal structure is not known.

3.8 Magnetic Field

No data exists on the magnetic field associated with the satellites. However the supposedly large magnetic field of Jupiter may have influenced the formation and position of the satellites and may also mask the individual magnetic fields.

4. THE SATELLITES OF INTEREST

The majority of information and knowledge of the satellites is restricted to the four largest in group 1. It would seem natural therefore to consider these as the ones of primary interest at present. Ganymede (J 3) is the largest and at 14 radii from Jupiter makes a reasonably amenable target. However its sidereal period is only of the order of 7 days which must make it difficult to intercept directly from Earth without a large investment in guidance and propulsion. Nevertheless it may well be easier to land on a large satellite than to penetrate the atmosphere of Jupiter and it may be considered as a useful observation platform having a fixed orientation with respect to Jupiter.

Io (J 1) and Callisto (J 4) can be considered as of similar interest to Ganymede but Amalthea (J 5) must be considered too close to Jupiter to be a reasonable target or to provide data which is intrinsically free from the influence of Jupiter (e. g. magnetic field).

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The irregular satellites have yielded little information from Earth observations and probably will be too small for further investigation from near Earth observations. A space probe would therefore seem a necessary way of obtaining very useful data particularly on their construction, composition and shape. Their small size and the difficulties of tracking their variable orbits would make direct interception difficult since even Jupiter based observations would require a 6" telescope to see them.

5. BASIC SCIENTIFIC QUESTIONS ON THE SATELLITES
OF JUPITER

The following basic questions are considered pertinent to our understanding of the origin and formation of the satellites of Jupiter and to their relationship with other bodies in the solar system including the asteroids, comets, and Jupiter itself.

- 5.1 How many satellites exist under the influence of Jupiter?
- 5.2 What are their masses, sizes, and densities?
- 5.3 What is their constitution and construction and how does this vary throughout the groups?
- 5.4 What is the relationship between the groups?
- 5.5 Do the irregular satellites show signs of fragmentation?
- 5.6 What is the relationship, if any, between the satellites and either the asteroids or comets?
- 5.7 Can the age of the satellites be estimated?
- 5.8 What are the surface features particularly of the larger satellites?
- 5.9 What is the magnetic field associated with them and how is this related to the Jovian field?

- 5. 10 Is there any evidence for past or present atmospheres or biological forms ?
- 5. 11 Is there any internal heat generation in the satellites ?
- 5. 12 What is the distribution of dust and micrometeorites in the satellite zone ?
- 5. 13 Can the color of the satellites be explained ?

6. MEASUREMENTS ON THE JOVIAN SATELLITES

The following types of measurements are suggested to provide initial data on the satellites.

6. 1 Visual Measurements (Photography and TV)

These are probably the most rewarding early measurements to be made on the satellites. The increased brightness of the objects together with the possibility of fairly high resolution from a passing probe could considerably increase our knowledge of their shapes, sizes and surfaces - especially the smaller ones. To deduce their sizes will lead to better estimates of their albedos and densities.

6. 2 Spectrometry and Polarimetry

The initial spectral measurements could concentrate on the detection of atmospheres and on the measurement of temperature. Polarimetry could be used to determine the gross nature of the surface but with limited accuracy. Useful data could be obtained on their colors and any variation in color.

6. 3 Magnetic Fields

Very useful data can be obtained on the magnetic fields in the whole environment of Jupiter with attention being paid to perturbations in the vicinity of the satellites. Interactions between fields should be watched

for, together with their influence on trapped radiation and dust.

6.4 Micrometeorites and Charged Particles

The measurement of both dust and charged particles in the whole vicinity of Jupiter will assist in the knowledge of the physics and dynamics of the solar system. In particular an opportunity presents itself for measurements in larger and probably more complex magnetic fields with a lower level of solar influence than is possible near the Earth.

6.5 Biology

Biological measurements, which must be considered in the latter stages of investigation, should be very interesting. The satellites are in a region where organic molecules are probably fairly abundant. The surface of Jupiter is certainly suspected of containing hydrocarbons formed during the atmospheric disturbances and electrical discharges.

7. IMPORTANCE OF SATELLITE DATA

The mere fact that Jupiter has satellites need not be excessively interesting but the fact that it has three distinct groups may well be so. Study of these groups may afford data on their origin both in terms of time and mechanism of formation. The Alfven theory suggests that the satellites represent a miniature solar system in their origin. Since a number of planet-satellite systems exist in just the one solar system, their study may reveal most information on the formation of the solar system. Jupiter is a giant planet, which itself is in a separate planetary group from the Earth and it has a considerably lower density than its major satellites. Its large magnetic field may have influenced the whole origin and history of the satellites. An interesting offshoot of an investigation of the Jovian satellites may

be the determination of relationships between themselves and the asteroids, or even possibly the comets and may assist in the integration of solar system data.

8. MISSIONS TO THE SATELLITES OF JUPITER

Before the origin of the solar system can be finally deduced many missions to many parts of the solar system will be necessary. The satellites of Jupiter will certainly be one of these. However they are not particularly amenable objects for detailed study since they are small masses near the large mass of Jupiter and in the case of the smaller ones have erratic orbits. Detailed measurements which are associated with individual satellites will require close approaches or even landings. Nevertheless the satellites of Jupiter are worthy of more consideration than simply part of the environment of Jupiter.

The initial missions to be considered should probably be linked with more comprehensive missions to Jupiter, probably using the same experimental equipment and using say the period spent near aphelion of a Jupiter orbit for satellite location and measurements. When landers are possible at distances from the Earth as large as Jupiter's it will be worth considering landing on a large fairly close satellite to observe Jupiter in considerable detail, besides collecting data from the satellite itself.

Table 1

THE SATELLITES OF JUPITER

Summary of Parameters which Characterize the Three Groups of Satellites

	Distance from Jupiter in terms of		Period of Revolution or Sidereal Period (days)	Diam (km)	Eccentricity of Orbit	Inclination or orbit to equator of Jupiter
	Jupiter radii	Semi-major axis of orbit (km)				
V (Amalthea)	2.540	181,500	0.49818	160-	0.003	0° 40' 17-
I (Io)	5.905	422,000	1.76914	3320-	0	0° 02' 67*
II (Europa)	9.401	671,400	3.55118	2880-	0.0003	0.4683*
III (Ganymede)	14.995	1,071,000	7.15455	4940-	0.0015	0.1833*
IV (Callisto)	26.379	1,844,000	16.68902	4680-	0.0075	0.2533*
VI	161	11,487,000	250.5662	120-	0.15798	27.6333-
VII	165	11,747,000	259.6528	40-	0.20710	24.7667-
X	165	11,861,000	263.55	20-	0.13029	29.0167-
XII	298	21,250,000	631.1	20-	0.16870	147. -
XI	315	22,540,000	692.5	24-	0.20678	164. -
VIII	330	23,510,000	738.9	40-	0.378	145. -
IX	332	23,670,000	758	22-	0.275	153. -

References: Nautical Almanac (1961)
 Astrophysical Quantities (Allen 1955)
 * Newburn (1961)

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